PROCEEDINGS

OF THE

FOURTH SYMPOSIUM

ON THE

NATURAL HISTORY OF THE BAHAMAS

Edited by
W. Hardy Eshbaugh

Conference Organizer
Donald T. Gerace

Bahamian Field Station, Ltd.
San Salvador, Bahamas
1992

Printed in USA by Don Heuer

ISBN 0-935909-41-9

STROMATOLITES OF STOUTS LAKE

William M. Elliott
Department of Biology
Hartwick College
Oneonta, N.Y. 13820

ABSTRACT

Species composition, community structure, growth rate, number and location of stromatolites from Stouts Lake, a hypersaline inland lake in the southcentral part of San Salvador Island, Bahamas, were studied. There were 745 stromatolites in a 750 m section along the western shore of the lake. They were typically found in water 0.5 m in depth with the mat portion protruding above the water's surface. The stromatolite mat was dominated by cyanobacteria. Three genera of the order Chroococcales were identified: *Chroococcus* (2 sps), *Gleocapsa*, and *Aphanotheca* and six genera of the Oscillatoriales: *Oscillatoria, Phormidium, Spirulina, Lyngbia, Microcoleus and Schytonema.* Two species of diatoms were also commonly found in the mats. A desmid, a green alga (*Dunaliella*) and a nematode occurred but were rare. Bacteria were common. The living mat was organzied into four distinct regions: Zone 1 was dominated by *Lyngbia*, zone 2 by *Microcoleus*, zone 3 by a salmon-colored photosynthetic bacterium and zone 4 by *Beggiotoa*, a sulfur-oxidizing bacterium. These stromatolites grew at a rate of about 1-mm per year.

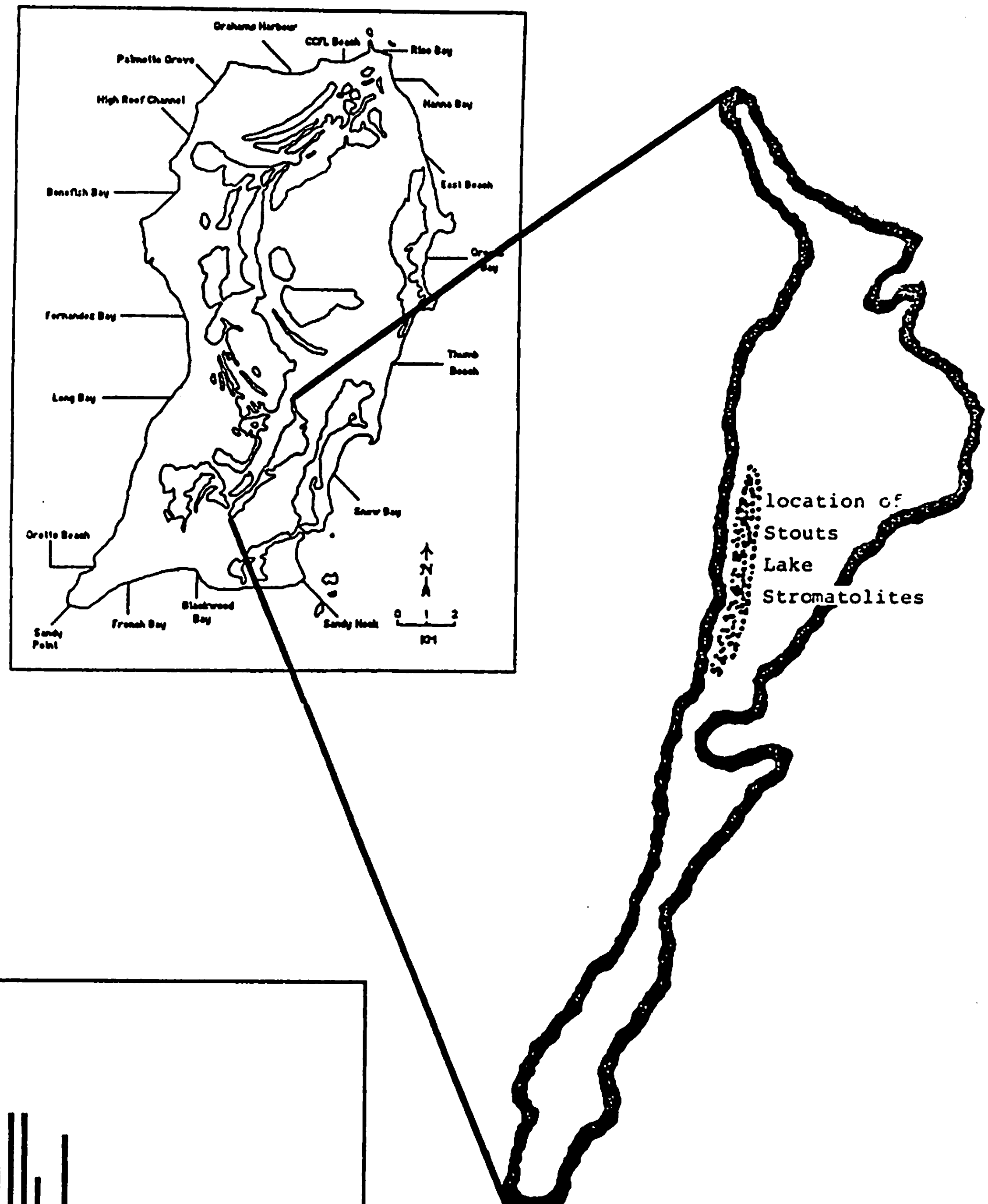
INTRODUCTION

The oldest known fossil stromatolites are found in cherts from the North Pole area of Western Australia and from the Swaziland supergroup of South Africa, with an age of between 3.3 and 3.5 billion years (Byerly et al., 1986; Walter et al., 1980). Stromatolites therefore represent the oldest firmly established biological deposits known from the geological record (Walter et al., 1980). Stromatolites were the dominant form of macroscopic life on earth for the next two billion years, reaching their zenith in the upper Riphean period about 750 million years ago. Then between 600 and 700 million years ago, the numbers and diversity of stromatolites decreased dramatically (Awramik, 1971). This relatively rapid decline in stromatolites corresponded to the rapid evolution of metazoans during this period. Stromatolites simply could not survive the grazing and burrowing animals that fed on their cyanobacterial mats. Garrett (1970) studied grazing by *Cerithidea* and other gastropods on the west coast of Andros Island where carbonate sediments are still being deposited. Gastropods tend to feed in herds, devouring all cyanobacteria. When certain areas of this littoral environment were protected from grazing, mats of cyanobacteria readily formed.

Though stromatolites no longer dominate the biota of our planet, they are still found in a variety of habitats that are free from grazers. Today they are found most commonly in hypersaline environments (Playford and Cockbain, 1976), though they are also found in hot springs (Walter, 1976) and even fresh waters (Eggleston and Dean, 1976). Probably the most extensively studied stromatolites are from Hamlin Pool in western Australia (Logan, 1961) and from Andros Island in the Bahamas (Monty, 1976).

A stromatolite begins as a mat formed by intertwining filaments of cyanobacteria (blue-green algae). Their intertwining filaments trap sediments, their gelatinous sheaths bind sediments and often their metabolism alters the carbonate equilibrium in such a manner that they actually precipitate sediments. Many species of cyanobacteria are motile and others are capable of producing gelatinous stalks. By these means, they are able to rise above these burying sediments. By this process a stromatolite, a series of sediment layers with a thin mat of cyanobacteria at the top, is formed. In precambrian times, stromatolites reached the size of the Pentagon (Schopf and Walter, 1982); today however stromatolites are rarely over a meter in height. The purpose of my project was to study the stromatolites of Stouts Lake on San Salvador

Figure 1. San Salvador Island, showing the location of stromatolites along the western shore of Stouts Lake.



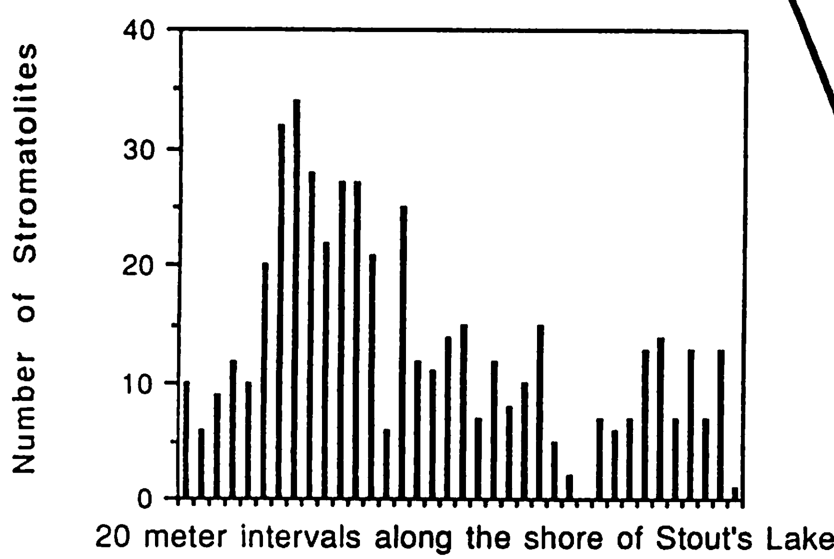


Figure 2. Distribution of stromatolites along the western shore of Stouts Lake.

Island in the Bahamas. I focussed on their species composition, community structure, growth rates, location and abundance.

LOCATION AND ABUNDANCE OF STOUTS LAKE STROMATOLITES

Stouts Lake is a hypersaline inland lake in the southcentral part of San Salvador Island. Actively growing stromatolites are restricted to a 750 m length along the western shore of the lake (Fig. 1). The stromatolites are typically located about 3 m from shore in water about 0.5 m deep, and they are often found in remarkably straight rows. The water of Stouts Lake is very turbid and the bottom is covered with organic ooze. As one walks along the bottom, one sinks into this sediment-rich ooze to a depth of about a quarter of a meter. In this region there are 745 stromatolites with cyanobacterial mats that rise above the water's surface. They differ in this regard from the stromatolites of Storr's Lake that are found almost entirely in the bottom ooze (Neumann et al, 1988). Stouts Lake stromatolites are generally evenly distributed over this zone, although they are in somewhat greater abundance in the northern part (Fig. 2).

SPECIES COMPOSITION OF STOUTS LAKE STROMATOLITES

Stromatolites are produced by complex communities of microorganisms, composed primarily of assemblages of cyanobacteria and eukaryotic microbes, particularly diatoms. Samples of the microbial mat of Stouts Lake stromatolites were collected using sterile cork borers and grown on appropriate media (Elliott, 1991). Attempts were made to isolate and identify the microbes making up this mat.

There are widely divergent views on the classification of cyanobacteria. Bold and Wynne (1985) recognize three orders based on the presence or absence of endo- or exospores and on whether the growth form is unicellular, colonial or filamentous. All cyanobacteria found in Stouts Lake stromatolites belong in the orders Chroococcales (spherical cells) and Oscillatoriales (filaments of cells). Three genera of Chroococcales were identified: *Chroococcus*, *Gleocapsa* and *Aphanotheca*.

Chroococcus (Fig. 3), as its name suggests, has spherical cells. They are usually unicellular or in aggregates because of failure of cells to separate after division. Their sheaths are thin, delicate and colorless. At least two species of Chroococcus were found in these stromatolites.

Gleocapsa (Fig. 4) is similar to *Chroococcus* except the cells are oval in shape and are surrounded by a gelatinous capsule. Cell division is in three planes.

Aphanotheca (Fig. 5) is composed of smaller, more rod shaped cells surrounded by copious amounts of gelatinous material. Like *Gleocapsa*, its cells divide in all three planes to produce three dimensional colonies.

Oscillatoriales are filamentious cyanobacteria that reproduce principally by hormogonia, although they can also produce akinetes or heterocysts. The cyanobacteria of this order dominated the mat community of these stromatolites: *Oscillatoria*, *Phormidium*, *Spirulina*, *Lyngbia*, *Microcoleus* and *Scytonema*. Each of these genera of cyanobacteria are highly motile, providing them with the ability to rise above entraping sediments.

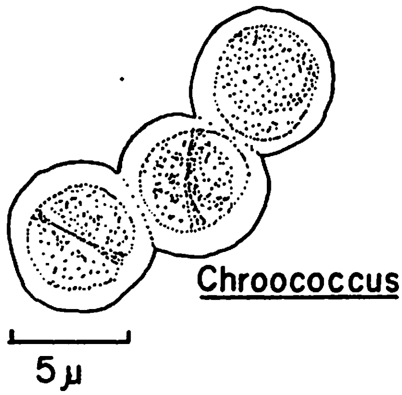
Oscillatoria (Fig. 6) form filaments that are cylindrical and unbranched (they divide in only one plane). Unlike other members of this order found here, their trichomes are surrounded by only a very thin delicate sheath.

Trichomes of *Phormidium* (Fig. 7) also have a thin sheath, but it is extremely hard and gelatinous. Members of this genus sometimes form *Phormidium* button stromatolites.

Spirulina is a helical member of this order. Its filaments have delicate transerse walls which are not visible in the light microscope.

Trichomes of *Lyngbia* (Fig. 9) have thick, many layered sheaths that are often impregnated with yellow or brown pigments. The unusually thick sheath and dark pigments protect it from ultraviolet irradiation.

Probably the most common species found in stromatolites in general belong to the genus *Microcoleus* (Fig. 10). The tricomes are composed of many twisted filaments each of which retains its individual motility. These intertwined filaments share a common gelations sheath.



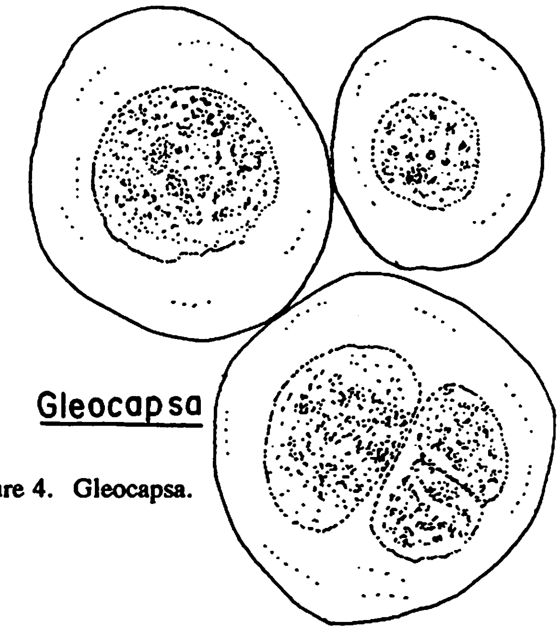


Figure 4. Gleocapsa.

Figure 3. Chroococcus. Camera lucida drawing. All illustrations of cyanobacteria are drawn to approximately the same scale.

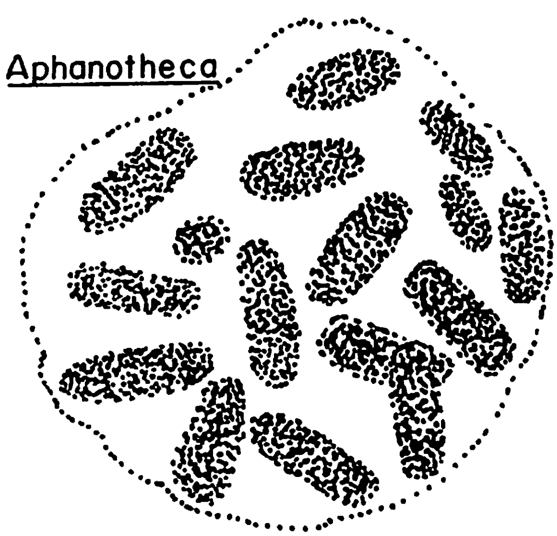


Figure 5. Aphanotheca.

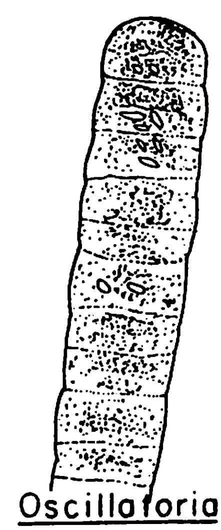


Figure 6. Oscillatoria.

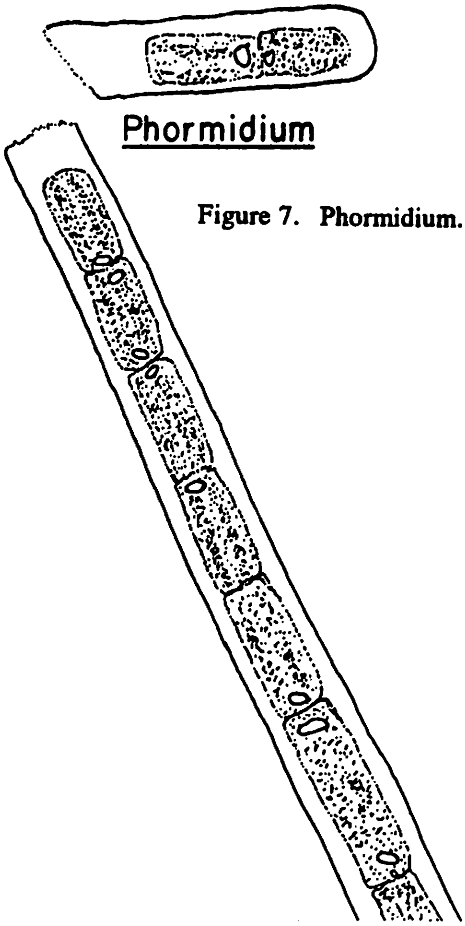


Figure 7. Phormidium.

Figure 8. Spirulina

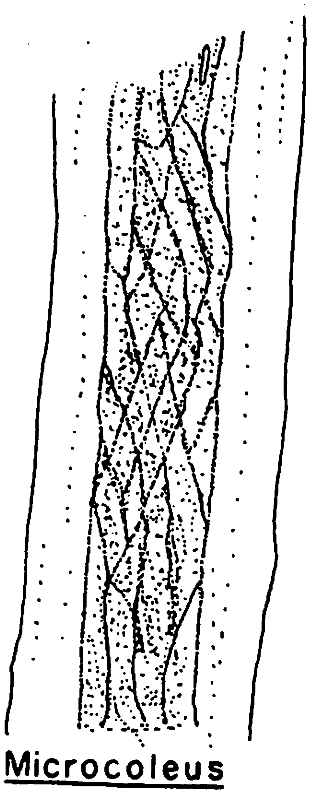


Figure 10. Microcoleus.

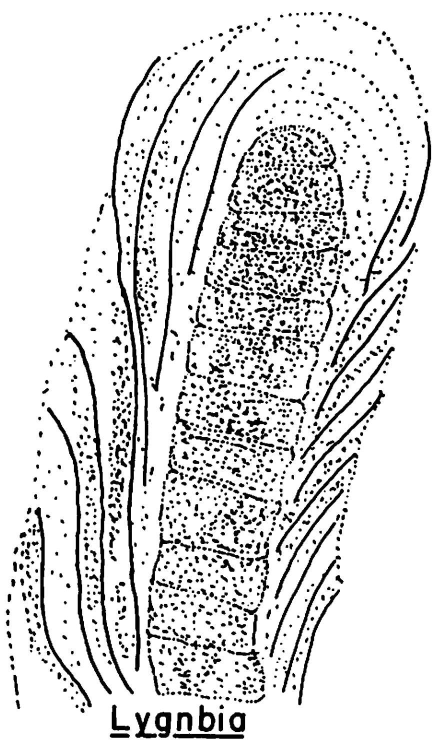


Figure 9. Lygnbia.

TABLE 1 : Species Composition of San Salvador's Stromatolites

Stouts Lake (present work)	Scytonema Mats (Pentacost, '88)	Storr's Lake (Neumann, '88)	Phormidium button (Pentacost, '88)	Plankton (Little & Great Lakes) (Marshall, '82)
Scytonema	Scytonema	Scytonema		Agmenellum
Phormidium	Phormidium	Phormidium	Phormidium	Anacystis
Spirulina	Schizothrix	Spirulina	Rivularia	Spirulina
Gleocapsa	Gleocapsa	Calothrix		Gomphospheraeria
Microcoleus		Microcoleus		Nostoc
Aphanotheca	Johannsbaptista			Johannsbaptista
Oscillatoria	Calothrix			Oscillatoria
Chroococcus				Coccochloris
Lyngbia				Lyngbia
diatoms (2 sp)	diatom: Nitzchia	diatom: Navicula		diatoms (16 sp)
desmid				
Dunaliella				
nematode				

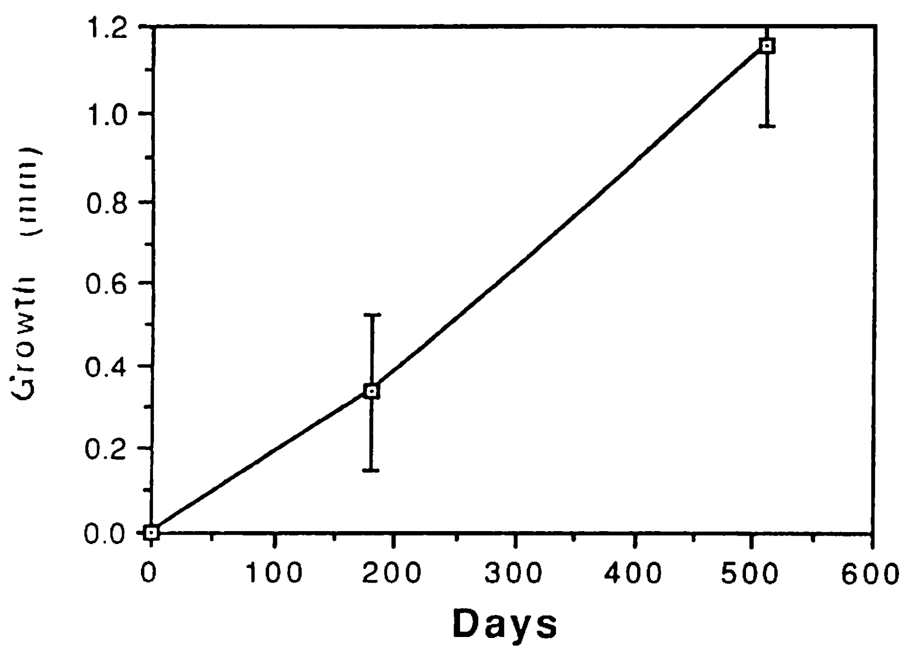


Figure 12. Growth rate of stromatolites between January, 1990 and June, 1991.

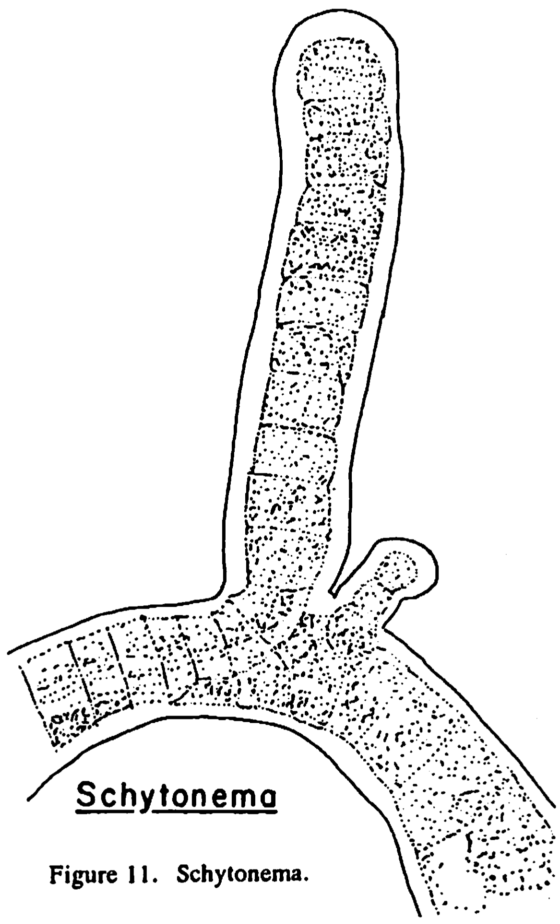


Figure 11. Schytonema.

Schytonema (Fig. 11) is unusual in that it forms false branches, typically near a heterocyst. These branching filaments are surrounded by a thick gelatinous sheath.

Although the species of cyanobacteria described above clearly dominate the mat forming community of Stouts Lake stromatolites, several species of eukaryotic microbes were also found. Two species of diatoms were very common in these stromatolites. Diatoms have been shown at times to play a dominant role in the formation of some stromatolites (Awramik and Riding, 1988; Winsborough and Golubic, 1987). Two green algae, a desmid and a member of the genus *Dunaliella* were also found, but were much less common than the diatoms. The ability of *Dunaliella* to survive and multiply even in saturated salt solution was the subject of my presentation two years ago at these meetings (Elliott, 1991). Nematodes were also occasionally found in these stromatolites. In addition a wide variety of bacteria were found, particularly in the lower layers of the stromatolites. Only the genus *Beggiatoa* was identified, although a salmon colored, photosynthetic bacterium was also isolated.

ZONATION OF STOUTS LAKE STROMATOLITES

As their name implies, stromatolites are layered structures. Not only are the sediments below the microbial mat layered, but the mat itself is composed of layers. Each layer is occupied by its own microbial community, adapted to the special ecological conditions of that region. Each zone has a characteristic color: Zone I is a dark brownish-green layer dominated by *Lyngbia*. The thick, pigment-impregnated sheath of this cyanobacterium protect it and the underlying zones from ultraviolet light. Zone II is a bright green layer dominated by *Microcoleus*. This bacterium is probably the dominant stromatolite builder in Stouts Lake. Zone III has a distinctive salmon pink color. It is dominated by photosynthetic, true bacteria. Zone IV is a black, anaerobic zone of decomposition. It appears to be dominated by *Beggiatoa*, a sulfur oxidizing bacterium.

Each of these zones is approximately 1 mm thick. The pattern of layering described here is remarkably similar to that described by Golubic (1976) for stromatolites found in the intertidal zone of the Persian Gulf. Layers below these zones are composed of relatively thick-grained sediments which were probably precipitated by the various species of cyanobacteria (Neumann et al., 1988).

The stromatolites of Stouts Lake are domed, unbranched mounds with ribs and gently convex lamina (Preiss, 1976). The most unusual feature of these stromatolites are prominant bumps on their top surface.

GROWTH RATES

As the microbial mat community rises above sediments that begin to bury it, a stromatolite increases in height. In order to deterimine the growth rate of stromatolites in Stouts Lake, I inserted a galvanized nail into each of 40 stromatolites in January of 1990. The head of the nail was 5-mm above the surface of the stromatolite. Growth measurements were then made in July, 1990 and June, 1991 (Fig. 12). Stouts Lake stromatolites grow at a rate of about 1-mm per year. At this rate of growth, these stromatolites may be about 700 years old. By radiocarbon dating, Neumann et al. (1988) found that Storr's Lake stromatolites were about 2,000 years old. Stromatolites on San Salvador are unique structure of considerable age. Every effort should be made to protect them.

COMPARISON WITH OTHER STROMATOLITES FROM THE BAHAMAS

Stromatolites have been found in a variety of habitats thoughout the world. They have been found on every continent including Antarctica (Parker and Wharton, 1983). However, stromatolites receiving the greatest scientific attention have been those of Hamlin Pool in Western Australia (Logan, 1961) and those of the Bahamas. The seminal work of Maurice Black (1933) on stromatolites from Andros Island provided what was to become a very influential model for interpreting modern stromatolites (Schopf and Walter, 1982). These stromatolites have been the subject of continuing studies. For example Cao and Xue (1985) studied stromatolites from a supratidal freshwater marsh in the northwesterm part of Andros, and Monty (1967) studied marine stromatolites in the eastern part of this island. Stromatolites have also been found in subtidal flats on Abaco (Neumann et al., 1970), on Exuma (Dill et al., 1986) and on Eleuthera (Dravis, 1983).

In addition, several other types of stromatolites have been reported from San Salvador Island. *Phormidium* buttons have been found in Graham's Harbor (Penticost, 1988). They are finely laminated stromatolites on subtidal beach rock, measuring 1.5 to 4 cm in height. They are composed almost entirely of *Phormidium*. Stromatolites begin as cynobacterial mats that bind, trap or precipitate sediments. Flat, polygonal mats of *Scytonema* can entrap sediments and have been found widely distributed over the Island (Pentacost, 1988). These mats might well represent incipient stromatolites. The most extensively studied stromatolites on San Salvador Island have been those from Storr's Lake (Neumann et al., 1988). They studied stromatolites in the bottom ooze near Cactus Island in this lake. They showed that these stromatolites have the ability to precipitate magnesium carbonate. Table I compares the species composition of the various types of stromatolites found on San Salvador Island. In general, the species of cyanobacteria found in San Salvador's stromatolites are quite different from the planktonic members of this group (cf. Marshall, 1982). Those of Stouts Lake are the largest and most species rich on the island.

ACKNOWLEDGEMENTS

Dr. N.B. Elliott assisted with every aspect of this study: collection of materials, survey of stromatolites, manuscript preparation, and some of the illustrations. I thank Dr. D.T. Gerace, Executive Director of the Bahamian Field Station, for assistance with logistics. Financial support was provided by grants from Hartwick College and The Bahamian Field Station.

BIBLIOGRAPHY

Awramik, S.M. 1971. Precambrian columnar stromatolite diversity: reflection of metazoan appearance. Science 174: 825-827.

Awramik, S.M., and R. Riding. 1988. Role of algal eukaryotes in subtidal columnar stromatolite formation. Proc. Natl. Acad. Sci. 85: 1327-1329.

Black, M. 1933. The algal sediments of Andros Island, Bahamas. Phil. Trans. Roy. Soc. Lond. B. 222: 165-192.

Bold, H.C., and M.J. Wynne. 1985. Introduction to the Algae (2nd ed). Prentice-Hall, New Jersey.

Byerly, G.R., D.R. Lowen and M.M. Walsh. 1986. Stromatolites from 3300 - 3500 million-year old Swaziland supergroup, Barberton Mountain Land, South Africa. Nature 319: 489-491.

Cao, R. and Y. Xue. 1985. Biological and lithological features of modern stromatolites in Bahamas. Acta Geol. Sin. 59: 203-212 (abstract only).

Dill, R.F., E.A. Shinn, A.T. Jones, K. Kelly and R.P. Steinen. 1986. Giant subtidal stromatolites forming in normal salinity water. Nature 324: 55-58.

Dravis, J.J. 1983. Hardened subtidal stromatolites, Bahamas. Science 219: 385-386.

Eggleston, J.R., and W.E. Dean. 1976. Freshwater stromatolitic bioherms in Green Lake, New York. IN: M.R. Walter (ed). Stromatolites. Elsevier, N.Y., pp. 479-488.

Elliott, W.M. 1990. A green alga associated with stromatolites on San Salvador Island, Bahamas. IN: D.T. Gerace (ed). Proceedings of the Third Symposium on Botany of the Bahamas. Bahamian Field Station, pp.7-16

Golubic, S. 1976. Taxonomy of extant stromatolite-building cyanophytes. IN: M.R. Walter (ed). *Stromatolites*. Elsevier, N.Y., pp. 127-140.

Garrett, P. 1970. Phanerozoic stromatolites: Noncompetitive ecological restriction by grazing and burrowing animals. Science 169: 171-173.

Logan, B.W. 1961. Cryptozoan and associated stromatolites from the recent, Shark Bay, Western Australia. J. Geol. 69: 517-533.

Mann, C.J., and W.M. Nelson. 1989. Microbialitic structures in Storr's Lake, San Salvador Island, Bahama Islands. Palaios 4: 287-293.

Marshall, H.G. 1982. Phytoplankton composition from two saline lakes in San Salvador, Bahamas. Bull. Marine Science 32: 351-353.

Monty, C.L. 1967. Distribution and structure of recent stromatolitic algal mats, eastern Andros Island, Bahamas. Ann. Soc. geol. Belg. 90: 55-100.

Neumann, A.C., B.M. Bebout, L.R. McNeese, C.K. Paull and H.A. Paerl. 1989. Modern stromatolites and associated mats: San Salvador, Bahamas. IN: J.E. Mylroie and D.T. Gerace (eds). *Proceedings of the Fourth Symposium on the Geology of the Bahamas*. Bahamian Field Station, pp. 235-251.

Neuman, A.C., C.D. Gebelein and T.P. Scoffin. 1970. The composition, structure and erodability of subtidal mats, Abaco, Bahamas. J. Sediment. Petrology 40: 274-297.

Parker, B.C., and R.A. Wharton. 1983. Unique stromatolitic algal-microbial mat communities of the antarctic dry valley oasis lakes. I. Distribution, species composition and morphology. J. Phycol. 19(suppl.) 7.

Pentecost, A. 1989. Observations on the Scytonema mats of San Salvador, Bahamas. IN: J.E. Mylroie and D.T. Gerace (eds). *Proceedings of the Fourth Symposium on the Geology of the Bahamas*. Bahamian Field Station, pp.295-302.

Pentecost, A. 1989. Discovery of Phormidium stromatolites in Grahams Harbour, San Salvador, Bahamas. IN: J.E. Mylroie and D.T. Gerace (eds). *Proceedings on the Fourth Symposium on the Geology of the Bahamas*. Bahamian Field Station, pp. 303-304.

Preiss, W.V. 1976. Basic field and laboratory methods for the study of stromatolites. IN: M.R. Walter (ed). *Stromatolites*. Elsevier, N.Y., pp. 5-14.

Schopf J.W., and M.R. Walter. 1982. Origin and early evolution of cyanobacteria: The geological evidence. IN: N.G. Carr and B.A. Whitton (eds). *The Biology of Cyanobacteria*. U.C. Press, Berkeley, 543-564.

Walter, M.R., R. Buick and J.S.R. Dunlop. 1980. Stromatolites 3,400-3,500 Myr old from the North Pole area, Western Australia. Nature 284: 443-445.

Winsborough, B.M. and S. Golubic. 1987. The role of diatoms in stromatolite growth: Two examples from modern freshwater settings. J. Phycol. 23: 195-201.